that charge independence in the conventional sense holds true, and that the baryon spectrum is complete.

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[1] A. Pais, Phys. Rev. **110**, 574 (1958), quoted here as I.
[2] The symmetries and degeneracies considered by M. Gell-Mann, Phys. Rev. **106**, 1296 (1957) and J. Schwinger, Ann. phys. **2**, 407 (1957) in their treatment of the π couplings, actually correspond to an invariance with respect to the direct product of three unitary unimodular groups.
[3] d'Espagnat, Prentki, and Salam, Nuclear Phys. **3**, 446 (1957), Eq. (2.1).
[4] Apart from the self-energy terms. Not all six terms are needed for the argument.

Decay of *K* Mesons as a Test of the Universal Fermi Interaction*

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On the basis of current experimental evidence, there is no distinction between μ mesons and electrons other than a difference in rest mass. Electromagnetic interactions are identical since electrons and μ mesons have the same charge, and the hypothesis of a universal Fermi interaction, which asserts that they couple in exactly the same way in the weak interactions, has received considerable support by comparing β-decay phenomena with the decay of free μ mesons and μ capture in nuclei. An at least equally fruitful series of experiments for reassuring one about the validity of the universal interaction idea is the analysis of the decays of π and K mesons into electrons and μ mesons. The details of such individual decays are not easily obtained theoretically, since they presumably involve strongly coupled virtual particles; however, the ratio of decay rates into electron modes and μ-meson modes may often be calculated exactly with no assumptions beyond saying that the weak interaction is local and may be treated in first order, and that the weak interaction is the same for electrons and μ mesons.[1]

If the universal coupling is taken as $V\pm A$, such analyses predict theoretically that in most cases the electron decay mode should be far less prevalent than the μ-meson mode, and (qualitatively at least) experiments support this conclusion. The only experimental situation in which the electron decay mode and the μ-meson decay mode are both actually observed is in the K_{e3} and $K_{\mu3}$ decays of K^+ mesons. It would seem to be valuable, therefore, to use this process as a further test of the universal interaction hypothesis.

Decays into electrons are observed in the process

$$K^+\rightarrow e^+ + \nu + \pi^0.$$

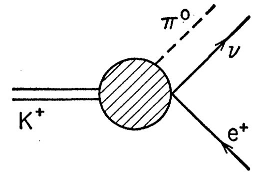

Fig. 1. Diagram representing the decay $K^+\rightarrow e^+ + \nu + \pi^0$.

This is to be compared with the decay

$$K^+\rightarrow \mu^+ + \nu + \pi^0$$

which is also observed. With the $V\pm A$ coupling hypothesis,[2] Lorentz invariance arguments give the following for the form of the electron-decay matrix element (see Fig. 1):

$$M(K\rightarrow e+\nu+\pi) = (\bar{u}_{p_\nu}|f p_K(1\pm i\gamma_5)+g m_e(1\mp i\gamma_5)|v_{p_e}). \quad (1)$$

Here f and g are functions of $p_K\cdot p_\pi/m_K$, m_K, and m_π, where p_k and p_π are the 4-momenta of the K meson and pion, respectively. If the K decays from rest one has $p_k\cdot p_\pi/m_k = E_\pi$, the energy of the pion. The Dirac spinors u_{p_ν} and v_{p_e} describe a neutrino of momentum p_ν and a positron of momentum p_e, respectively. If time-reversal invariance holds, f and g are real functions.

The decay rate then is given by

$$\frac{d^2w(K\rightarrow e+\nu+\pi)}{dE_\pi dE_e} = \frac{1}{(2\pi)^3}\frac{1}{4m_K} \times\{f^2 m_K^2(4E_eE_\nu - m_K^2 - m_\pi^2 + m_e^2 + 2m_KE_\pi) + g^2m_e^2(m_K^2+m_\pi^2-m_e^2-2m_KE_\pi) - 2fgm_em_K(2m_eE_\nu)\}. \quad (2)$$

Here E_e and E_ν are the positron and neutrino energies; we of course have

$$m_K = E_e + E_\nu + E_\pi. \quad (3)$$

On the assumption of a universal $V\pm A$ interaction, the decay rate for the process $K\rightarrow\mu+\nu+\pi$ is given by the same expression with the index e replaced by the index μ. Since the functions f and g depend *only* on E_π, and since they are the same in both the e- and μ-decay modes, it is possible to test the universal coupling hypothesis by measuring the μ-decay rate at a fixed value of E_π for two values of E_μ and thus determining f and g. Then the e-decay spectrum for the same value of E_π may be predicted uniquely and compared with experiment. A violation of this predicted spectrum by the experimental results must imply a violation of the assumption of a $V\pm A$ universal coupling.

At the present time, unfortunately, the experimental information is too meager to do this, but it is to be hoped that the data will exist before too long.

An estimate of the ratio of the total lifetime of the

K_{e3} and $K_{\mu 3}$ modes may be made from Eq. (2) by neglecting m_e (and m_μ) compared to m_k. This gives the ratio (accurate to probably 30%)

$$w(K\rightarrow e+\nu+\pi)/w(K\rightarrow\mu+\nu+\pi)\sim 1,$$

which is quite consistent with experiment.[3]

I would like to thank S. Drell for several valuable conversations.

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[1] Bogoliubov, Bilenky, and Logunov, Nuclear Phys. **5**, 383 (1958).
[2] R. P. Feynman and M. Gell-Mann, Phys. Rev. **109**, 193 (1956); E. C. G. Sudarshan and R. E. Marshak (to be published).
[3] For further discussion of the K_{e3} and $K_{\mu 3}$ decay modes, see A. Pais and S. B. Treiman, Phys. Rev. **105**, 1616 (1957); J. J. Sakurai, Nuovo cimento **5**, 649 (1958); J. J. Sakurai, Phys. Rev. **109**, 980 (1958).

Decays of the μ Meson in the Intermediate-Meson Theory*

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The idea of a universal Fermi interaction has received some attention recently, partly as a result of various proposed symmetry principles[1] which restrict the form of the 4-fermion interaction, and partly because of a number of experiments[2] which indicate that the couplings which appear in the β decay are $V-A$, in agreement with those already found in the μ decay. It has further been suggested that this universality may come about through the interaction of a current with itself by exchange of a heavy charged boson,[1] which will be referred to as an intermediate meson. One advantage of such a mechanism is that direct 4-fermion interactions involving 4-charged or 4-neutral fermions cannot arise through the exchange of such a boson. These interactions could lead to unobserved decays like $\mu^\pm\rightarrow e^\pm+e^++e^-$ and $K^\pm\rightarrow\pi^\pm+\nu+\bar{\nu}$. However, as we shall see, the existence of the decay $\mu^\pm\rightarrow e^\pm+e^++e^-$ to a small extent, as an indirect process, is implied by the intermediate-boson hypothesis in its usual form.

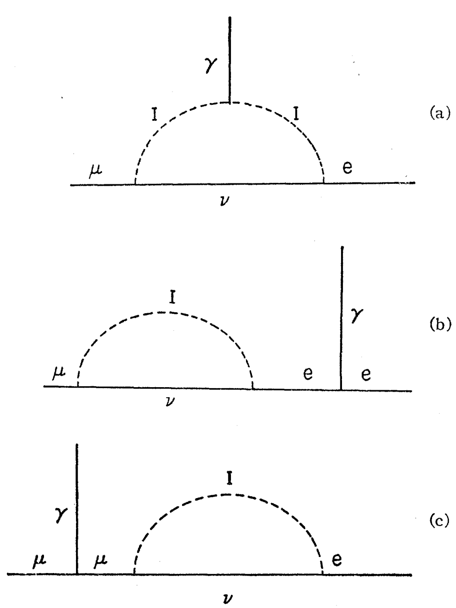

FIG. 1. Feynman diagrams for $\mu\rightarrow e+\gamma$ through an intermediate boson. I labels the intermediate boson field.

It is the purpose of this note to point out that the existence of such a heavy boson, with the properties required to give the known Fermi couplings, will itself lead to the occurrence of decays which are not found in nature, and which would not occur in any detectable amount if there are no intermediate bosons. Specifically, we consider the hypothetical decay $\mu\rightarrow e+\gamma$. This alternate decay mode of the μ has been looked for by Lokanathan and Steinberger,[3] who have found that the branching ratio for it compared to the ordinary μ decay,

$$\rho=R(\mu\rightarrow e+\gamma)/R(\mu\rightarrow e+\nu+\bar{\nu}),$$

is less than 2×10^{-5}.

If the intermediate meson exists and is coupled to the $\mu\nu$ and $e\nu$ pairs as has been suggested, then the decay $\mu\rightarrow e+\gamma$ can proceed by the following chain of virtual processes:

1. $\mu\rightarrow$intermediate meson and neutrino.
2. Intermediate meson$\rightarrow$intermediate meson+photon.
3. Intermediate meson+neutrino$\rightarrow$electron.

There are two similar chains in which the electron or μ meson emits the photons. The three Feynman graphs which represent this process in lowest order are given in Fig. 1.

The point to note[4] is that the coupling constant g_I for the interaction of the intermediate mesons with the fermions is proportional to the square root of the Fermi coupling constant G, and therefore the matrix element for the decay $\mu\rightarrow e+\gamma$ via the chain 1–3 will be of order Ge, whereas the matrix element for the ordinary μ decay is of order G, so that one would expect a measurable branching ratio for $\mu\rightarrow e+\gamma$. This is to be contrasted with the case when only the four-fermion couplings with 2 charged and 2 neutral fermions exist, where the matrix element for $\mu\rightarrow e+\gamma$ will involve at least G^2, and where the decay will therefore be very slow.

An evaluation of the graphs of Fig. 1 has been made for intermediate mesons of spin 1. The interaction of the intermediate mesons with leptons was taken as

$$g_I\{\bar{\psi}_\mu\gamma_\rho(1+\gamma_5)\psi_\nu\phi_\rho+\text{c.c.}\}+g_I\{\bar{\psi}_e\gamma_\rho(1+\gamma_5)\psi_\nu\phi_\rho+\text{c.c.}\},\quad(1)$$

where ρ is summed from 1 to 4, and ϕ_ρ are the 4-meson field operators. This interaction gives an effective 4-fermion coupling of the required $V-A$ form with